Potential Impacts of Sea-level Rise on the Coast

Invited talk to the
Massachusetts Coastal Hazards Commission

8 May 2006

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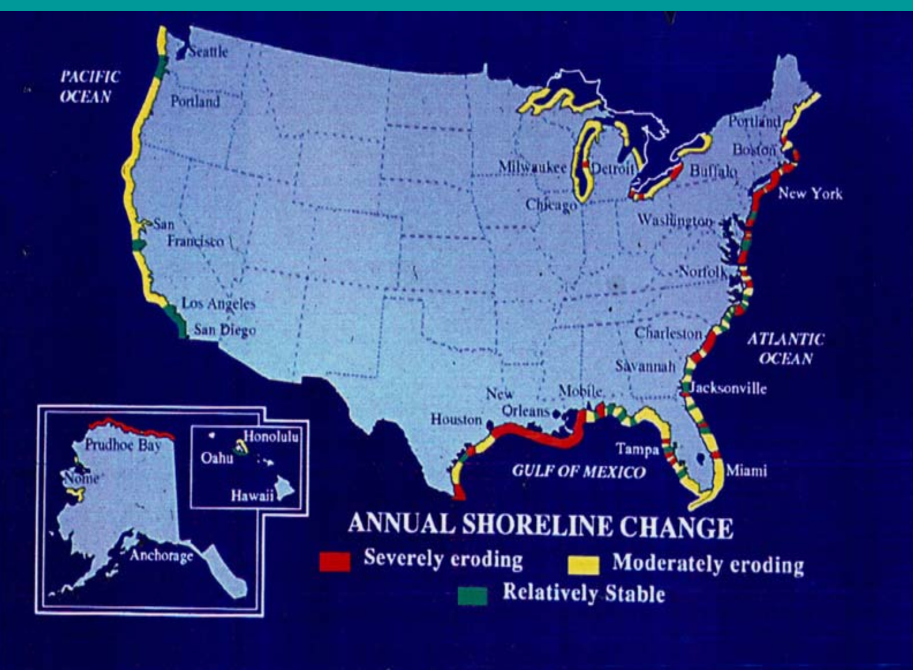
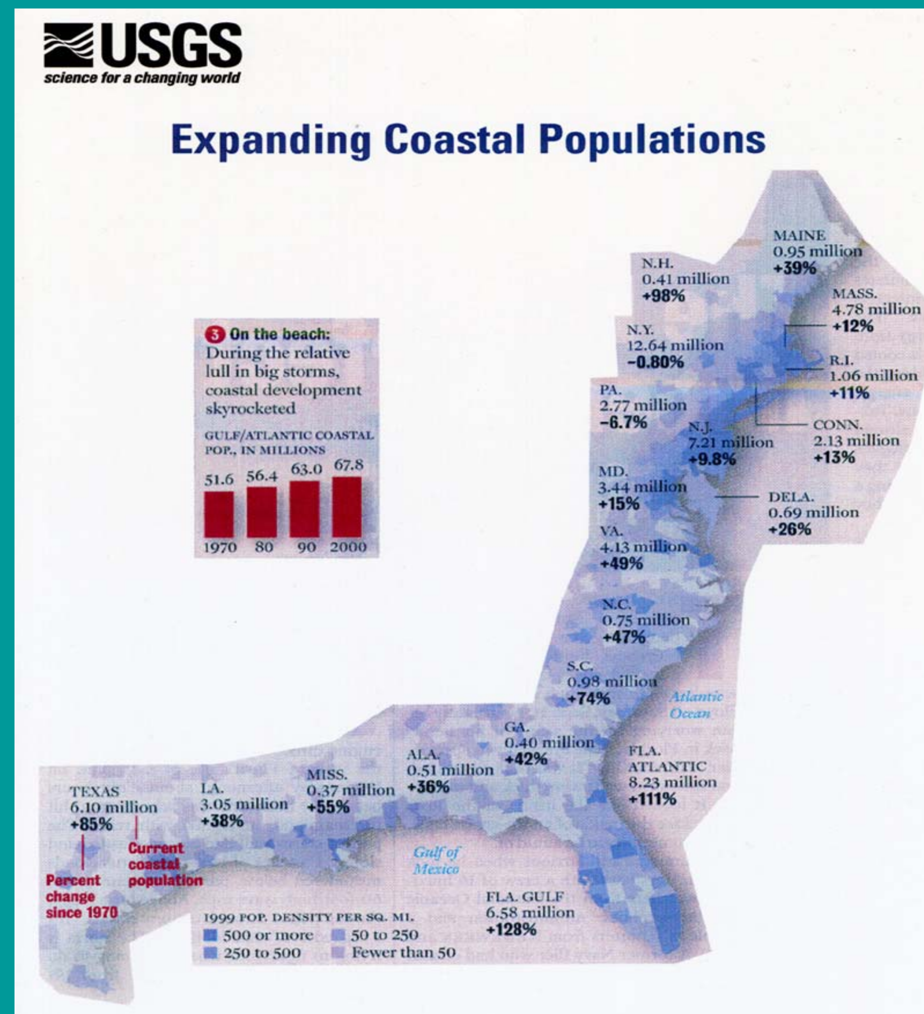
U.S. Geological Survey
Woods Hole Science Center, MA

Natural Coastal Hazards

- Catastrophic storms (hurricanes, Nor’easters)
  - storm-surge flooding
  - shoreline erosion
  - high winds
- Coastal erosion
- Global sea-level rise
- Land subsidence
- Global and regional climate change
- Earthquakes
- Tsunamis
- Landslides
- Volcanic activity

America's Coastal Crisis…. Coastal hazards and populations at risk are increasing





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Primary Factors and Processes Driving Coastal Change

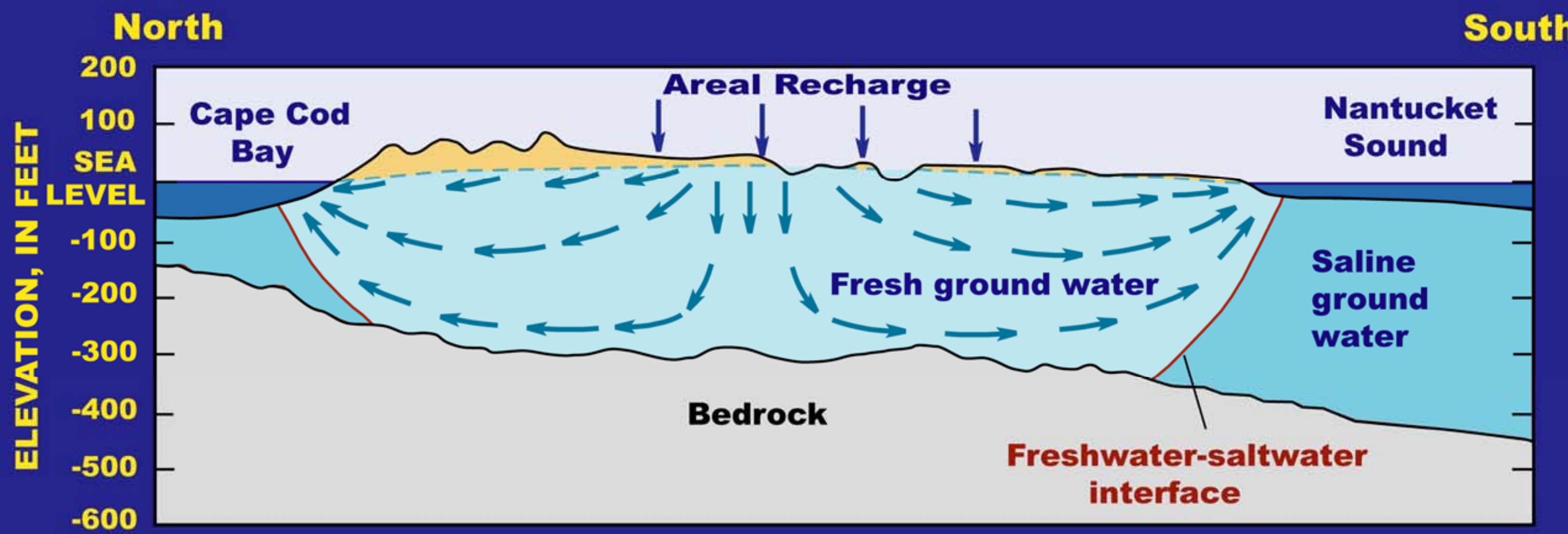
- Geologic framework and character
- Coastal plain geomorphology and slope
- Relative sea-level change
  - global change
  - land subsidence/uplift
- Major storm events
  - tropical storms/ hurricanes
  - extratropical storms
  - nor'easters
- Seasonal coastal processes
  - waves and tidal currents
  - winds
  - cold fronts and local storms
- Sediment budgets
  - sediment sources (headlands, bluffs)
  - sediment sinks (wash-over, inlets)
- Human activities
  - coastal engineering structures
  - dredging channels, inlets, canals
  - river modification (dams, levees)
  - fluid (oil-gas-water) extraction
  - climate change (SLR, storms)

Potential effects of sea-level rise on coasts

Greater potential impact

- Loss of coastal habitats and resources
- Increased beach-bluff-dune-marsh erosion
- Loss of recreation resources (beaches, marshes)
- Salt–water intrusion to water wells, septic systems
- Elevated storm-surge flooding levels
- Greater, more frequent coastal inundation
- Increased risk to urban infrastructure
- Greater risk to human safety & development

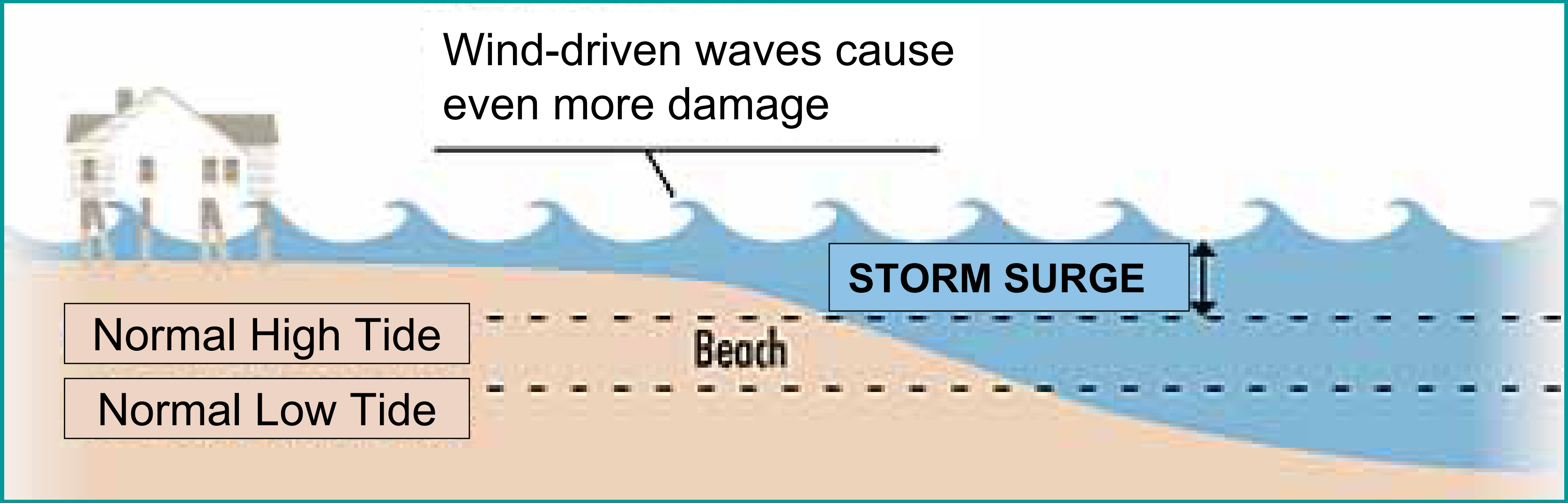
Schematic of sole-source ground water flow on Cape Cod

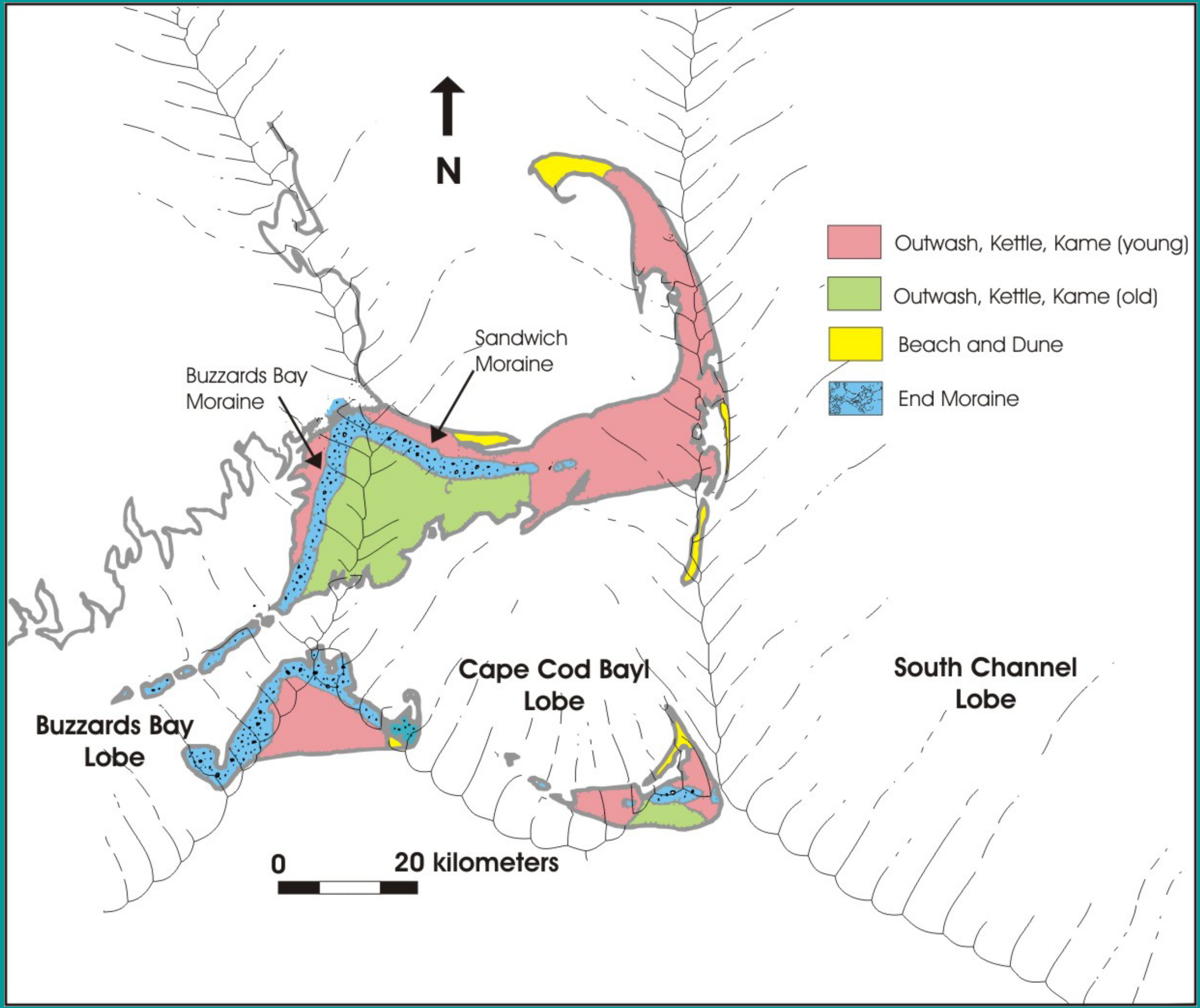


US Geological Survey

Coastal storm surge

- **Storm surge – temporary increase in water level due to wind and atmospheric pressure forces related to a hurricane**





Geologic map of Cape Cod and the Islands showing the maximum extent of glacial ice lobes ~18,000 yrs ago (Oldale, USGS)

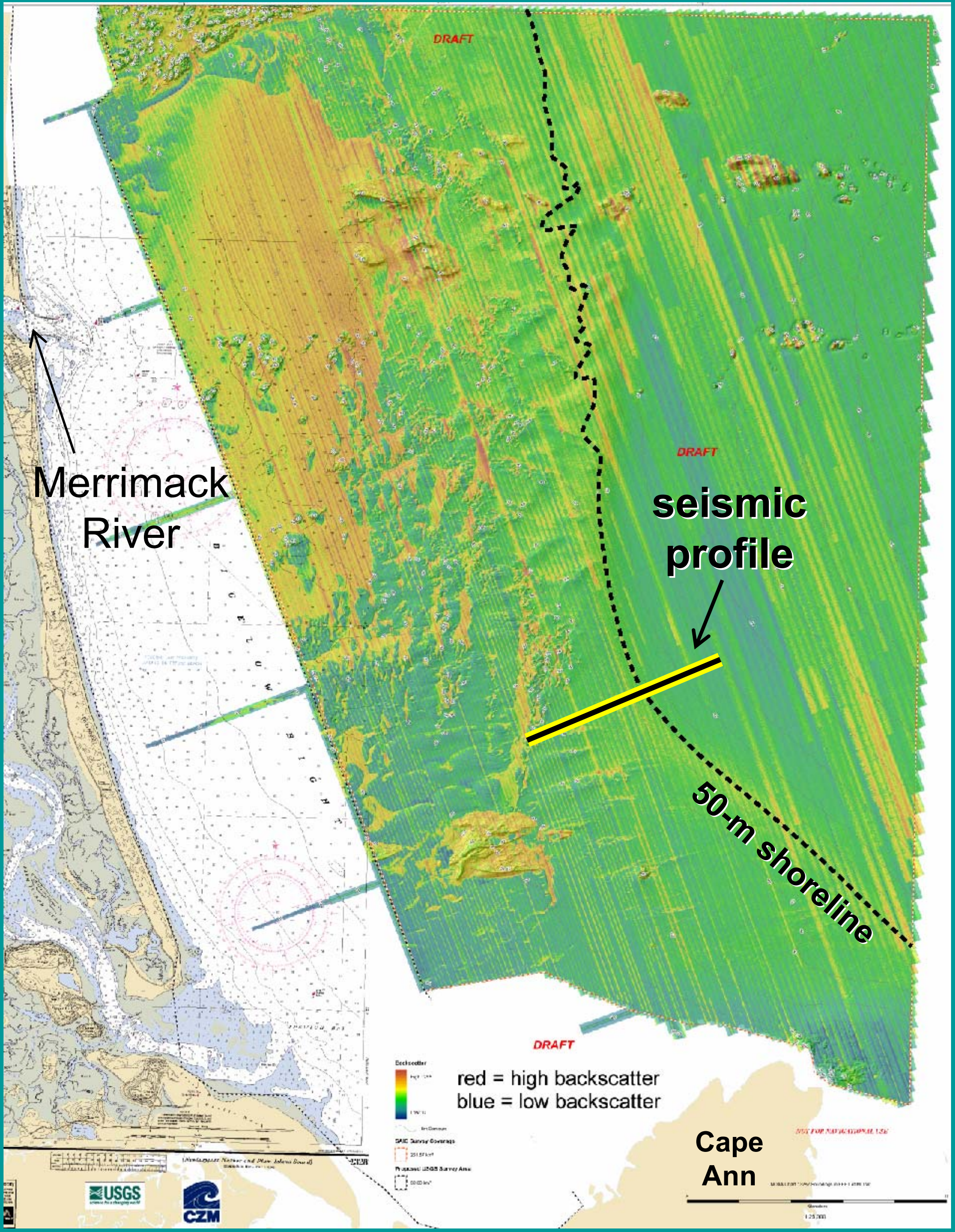
Sources of sea-level change data

- Coastal and offshore geologic record (seafloor features, age dating organic peat from sediment cores, coral reefs)
- Average rates of change from selected long period, high quality tide-gauge records (1850s- 2006)
- TOPEX/Poseidon and Jason-1 satellite altimeters, global coverage (1993-2006)

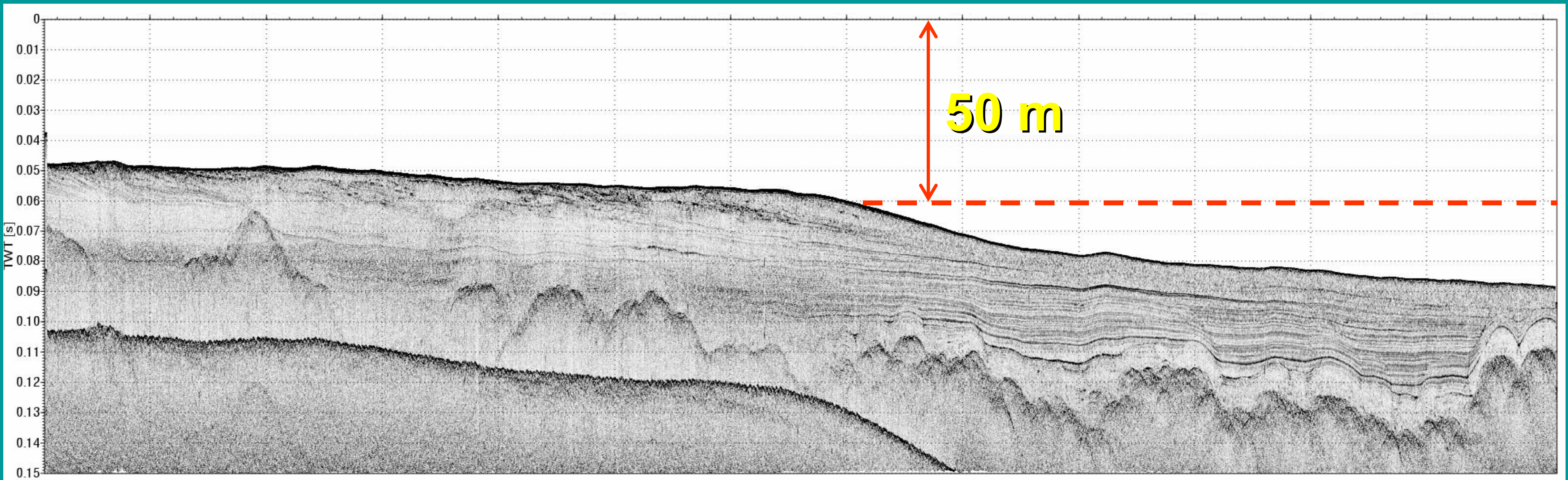
Backscatter map offshore of the Massachusetts coast based on the USGS/MCZM coop geologic mapping study

From W. Barnhardt, USGS

5 km (8 miles)

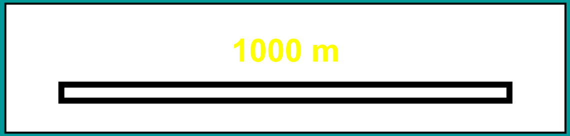


An ancient drowned delta seaward of the Merrimack River shows that sea level was about 50 m below present ~12,000 yr ago

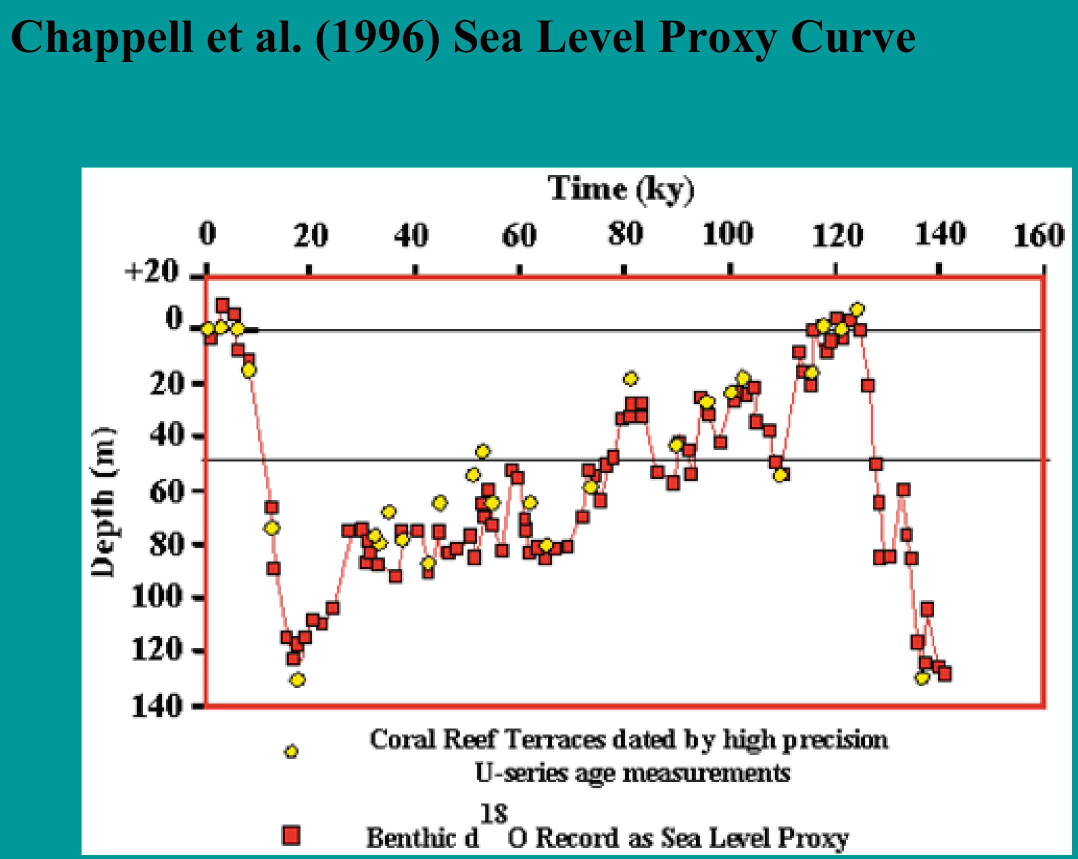


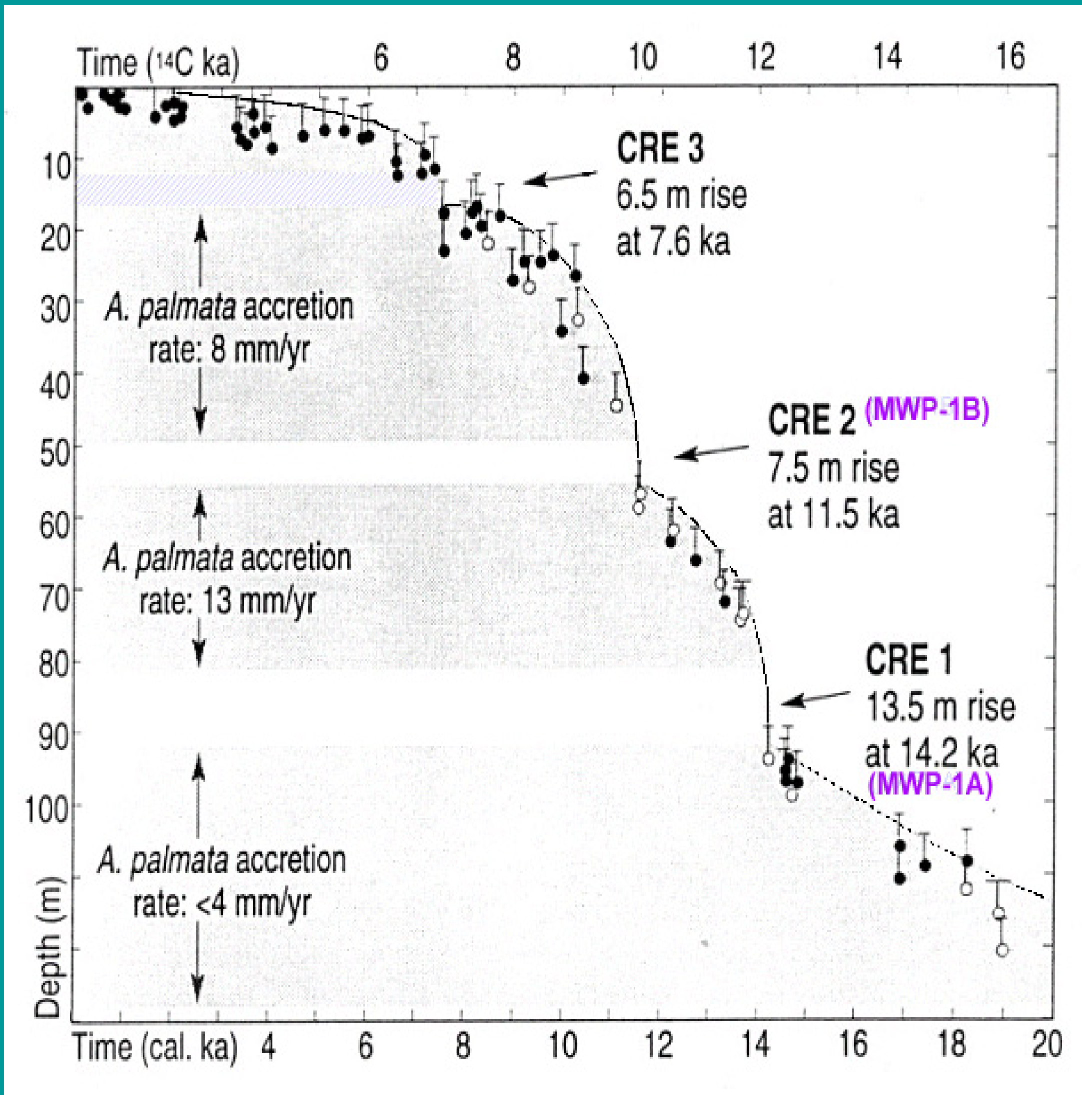
R/V Connecticut 05005 Edgetech 512i Chirp Line l112f1

From W. Barnhardt, USGS



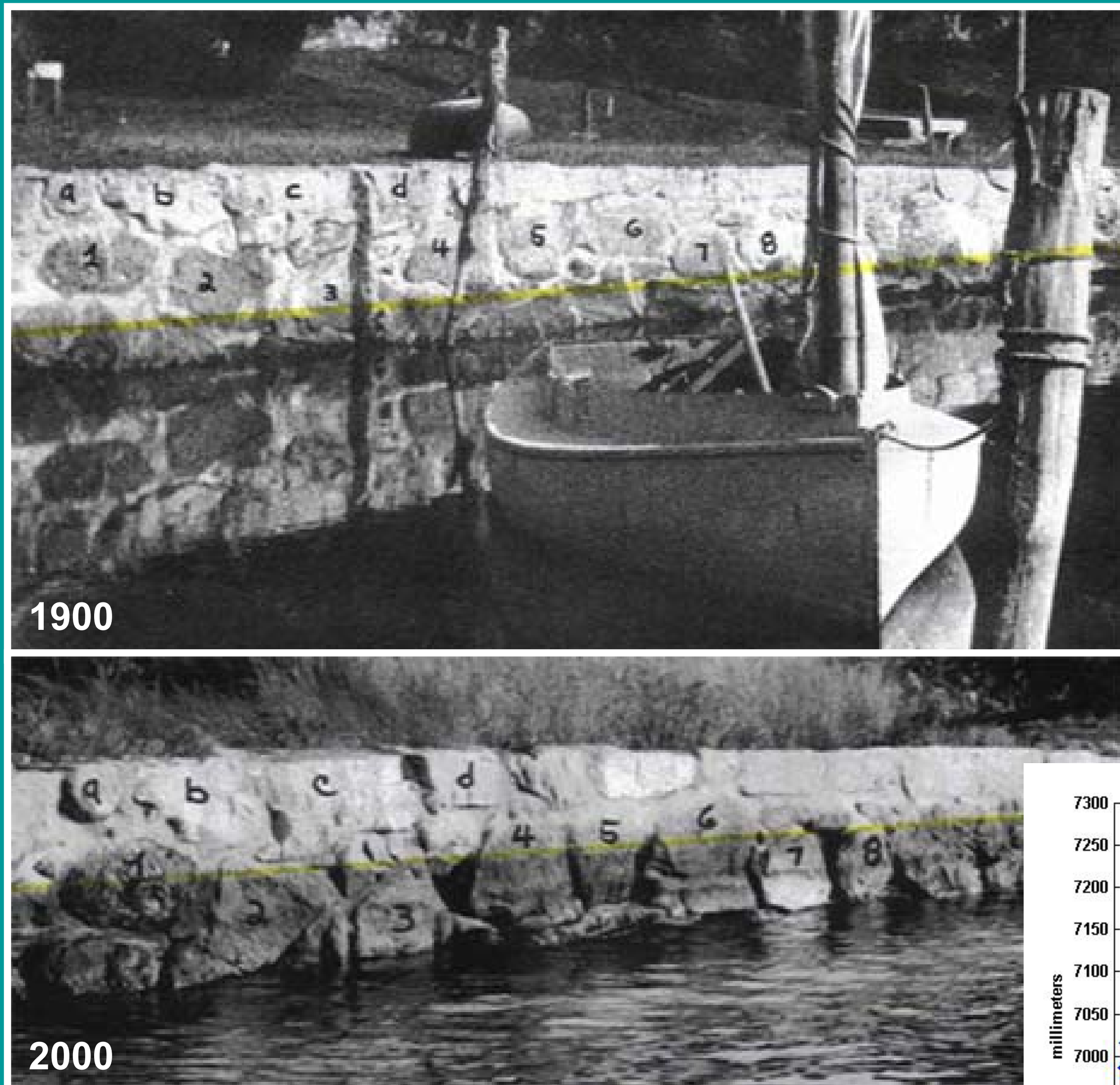
Global sea level change over the past 140k yrs based on coral age dating





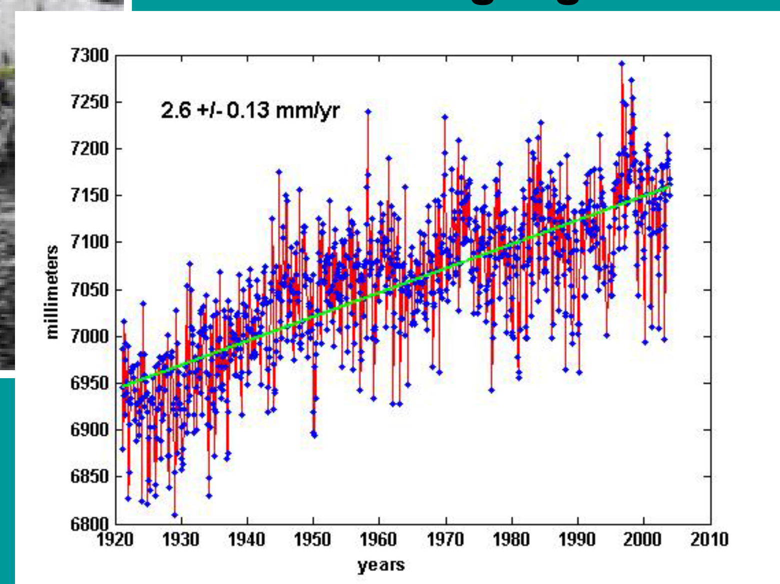
Global sea-level rise (~120m) over the past 20,000 years based on C14 dates and corals

Blanchon and Shaw (1995)



Mean relative sea-level rise for Woods Hole and Boston gauges has been 26 cm (10 in) over the past 100 years

Boston tide gauge record



(photo: J. Wilber)

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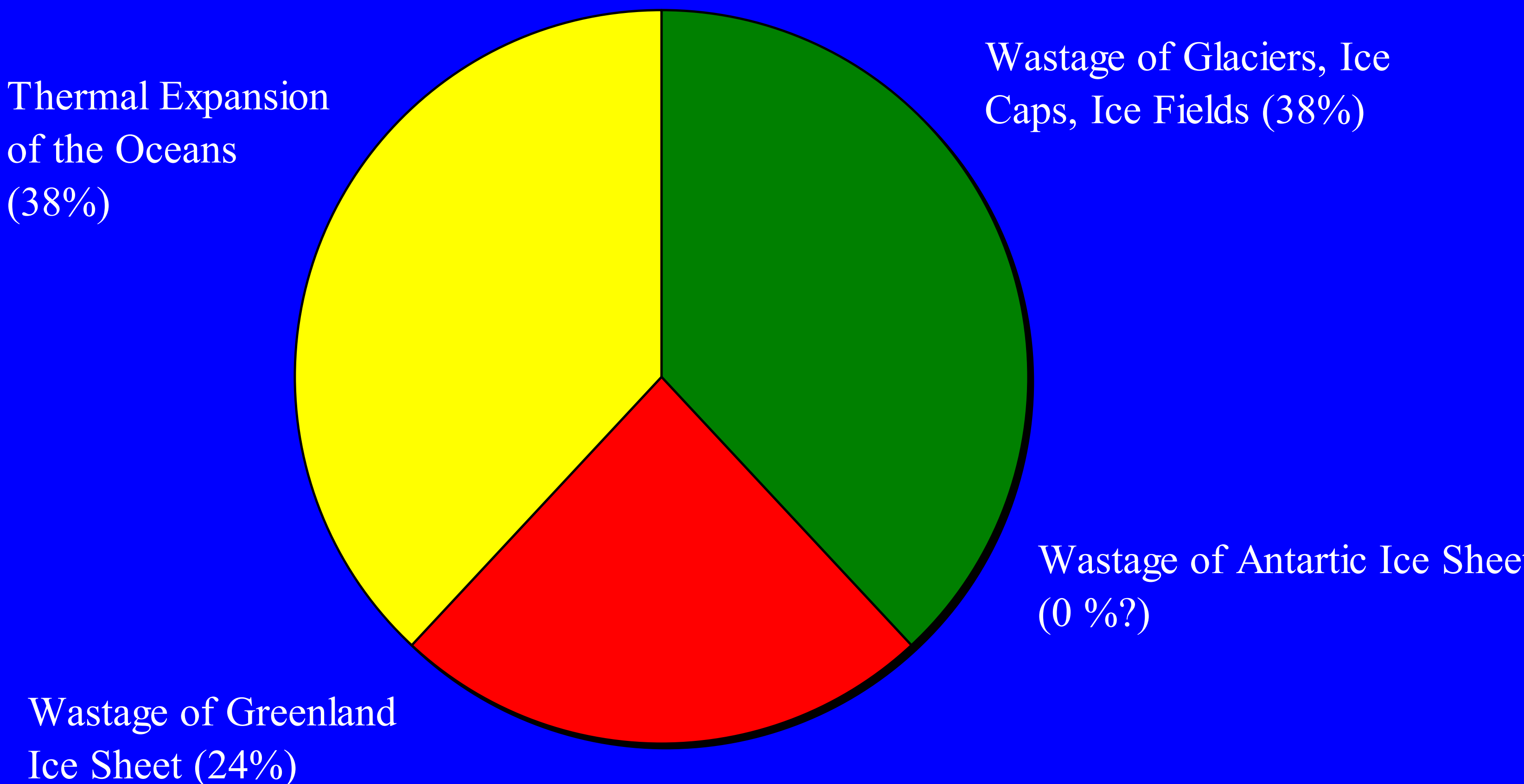
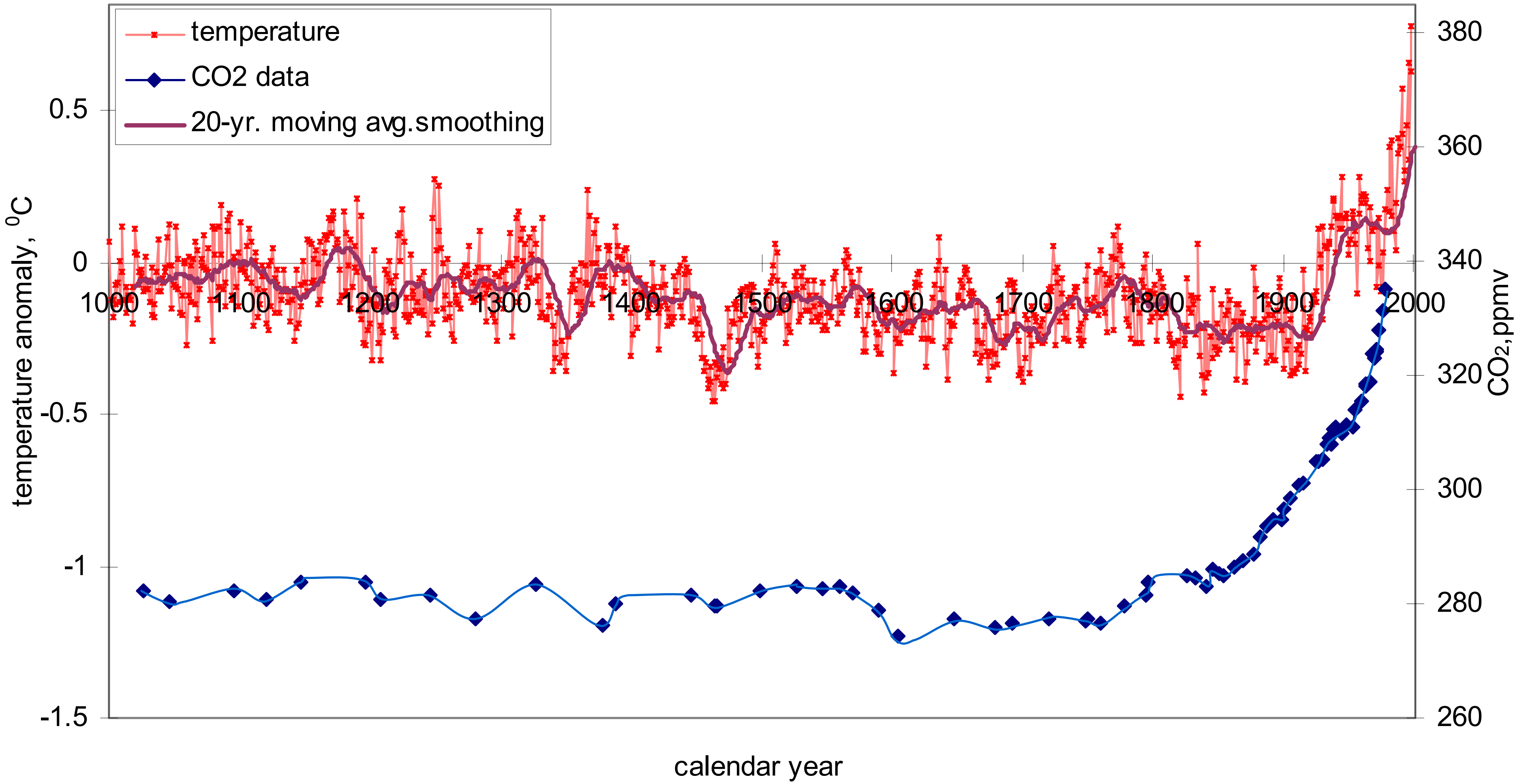
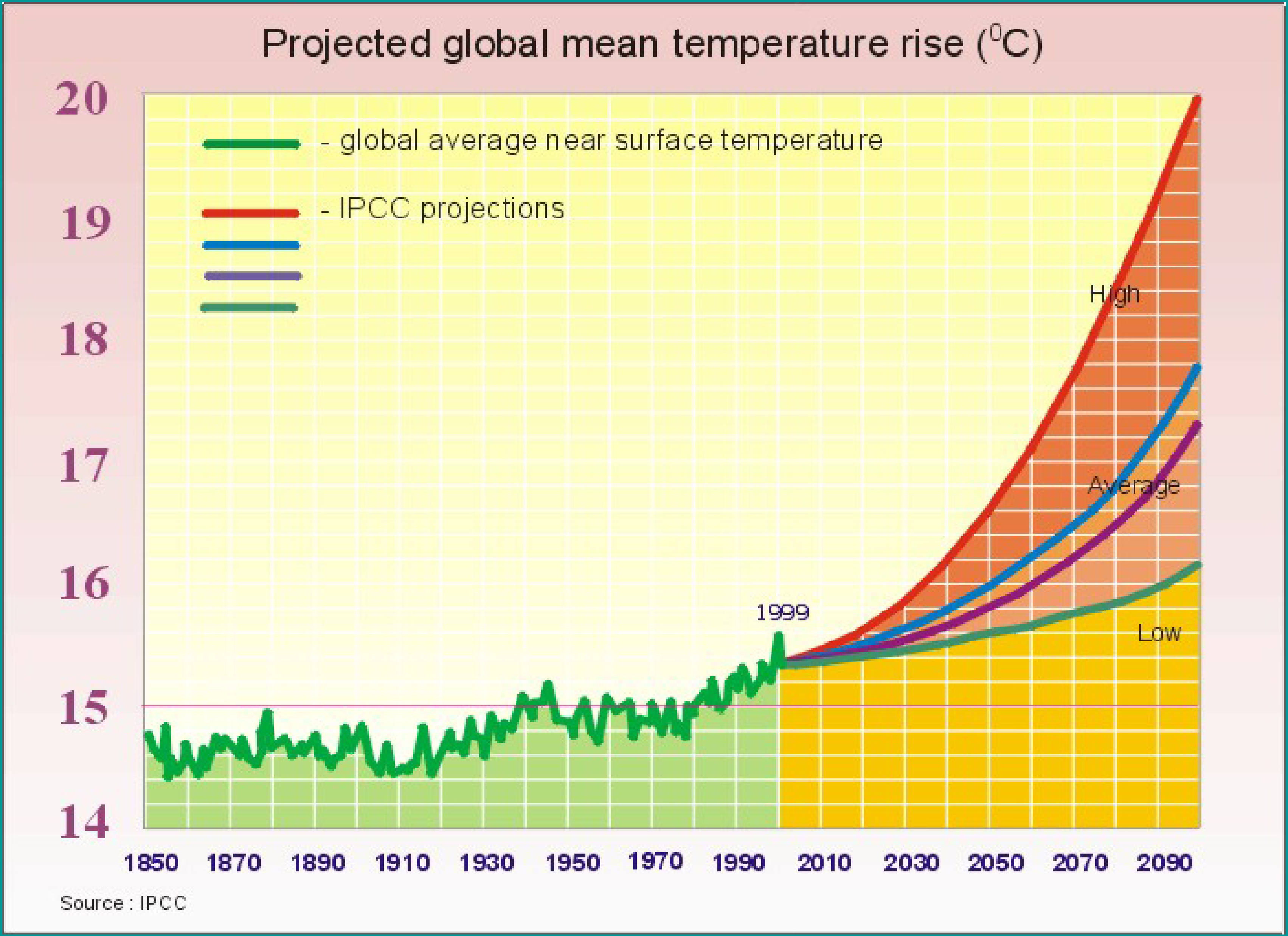
Best Estimates of Climate-Related Contributions to Eustatic Sea-level Rise (12 to 15 cm) Over the Last 100 Years



Millenial temperature reconstruction (Mann, 1999) compared to the CO_2 data from Taylor and Law domes

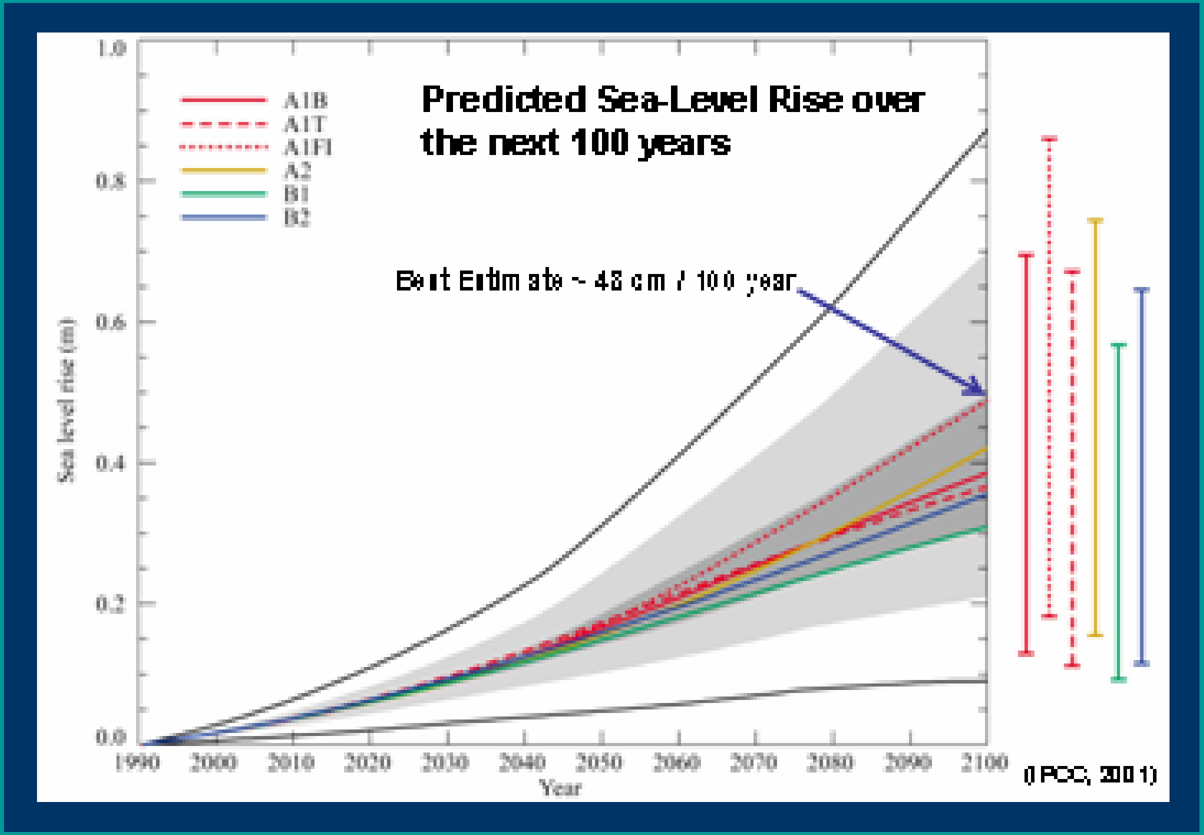




Projected global mean temperature rise (⁰C)
20
19
18
17
16
15
14
- global average near surface temperature
- IPCC projections
High
Average
Low
1999
1850
1870
1890
1910
1930
1950
1970
1990
2010
2030
2050
2070
2090
Source : IPCC

IPCC predictions of future sea-level rise,1990-2100, based on 7 global models and 6 climate scenarios (IPCC; Church, 2001)

Motivation for sea-level rise research



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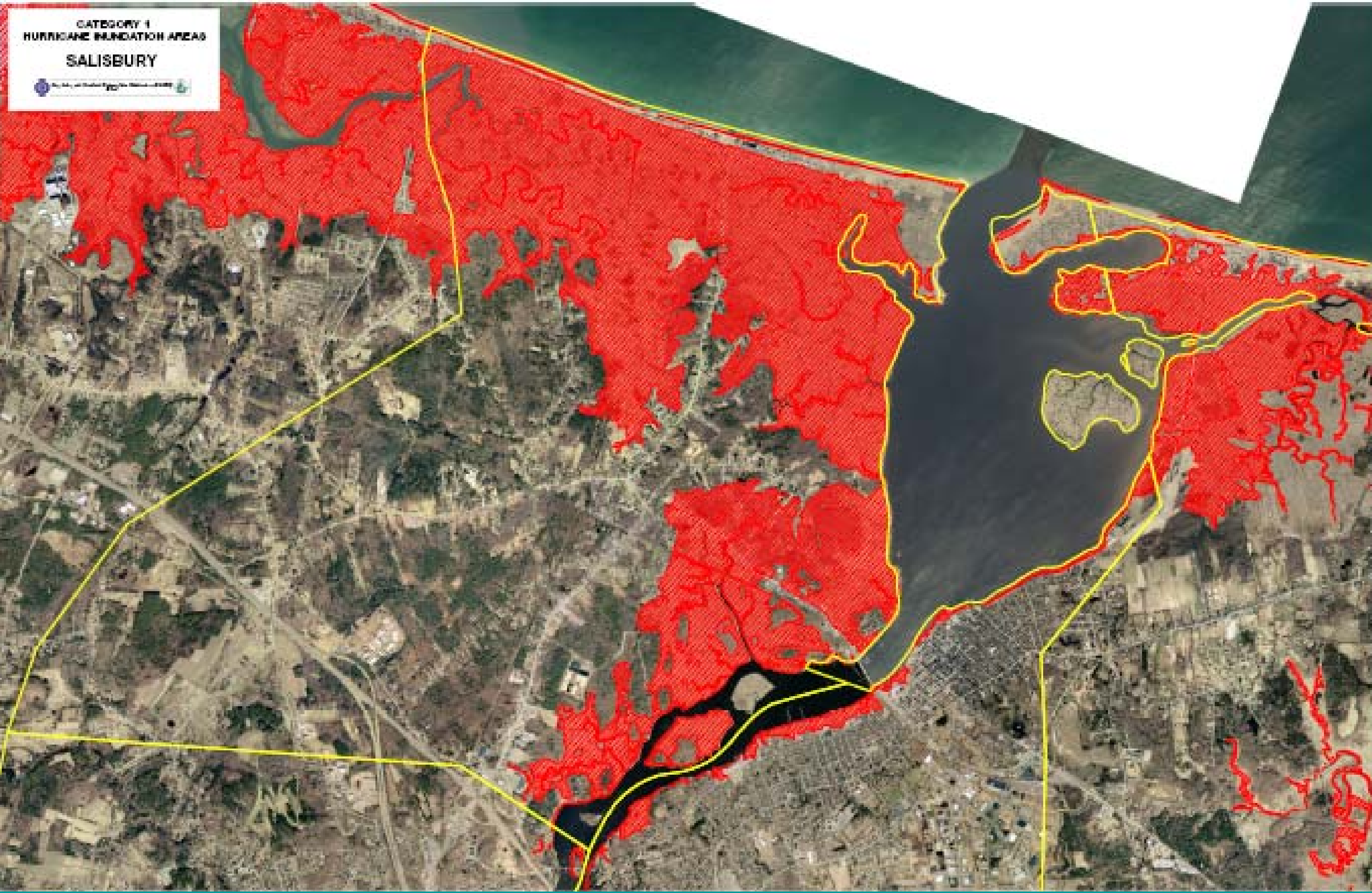
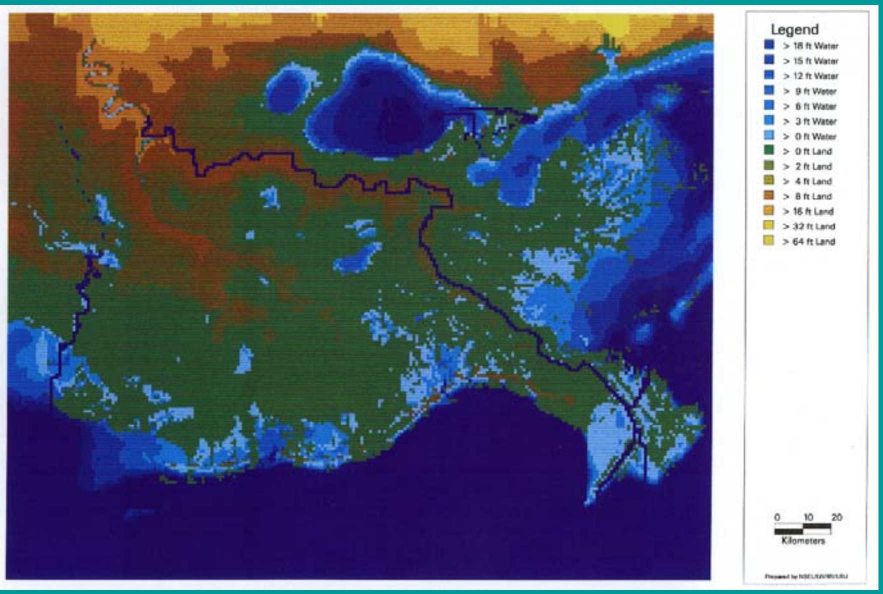
Current modeling approaches

- Inundation mapping using DEMs and various SLR scenarios (coarse data, ignores dynamic processes, sed budget)
- Historical shoreline trend extrapolation (assumes rates reflect all processes)
- Equilibrium profile (Brunn rule)
- Large-scale, variable time scales, geomorphic behavior (GEOMBEST)
- Coastal change hazard-scale mapping (4 levels)
- Coastal vulnerability index (6 variables)

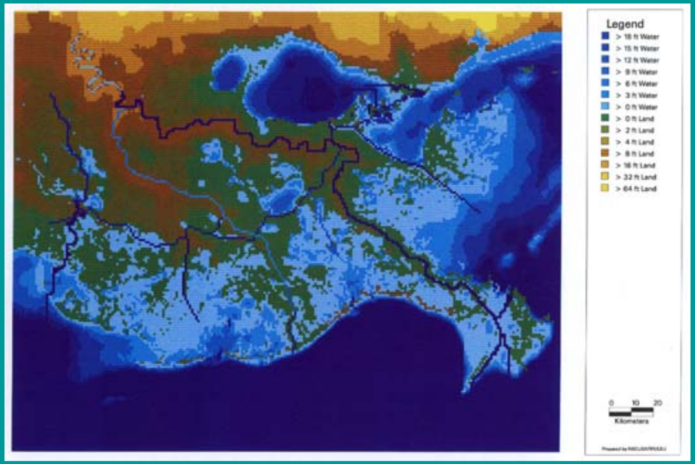


Example storm inundation map, Salisbury Beach (Mass Hazards Mitigation Plan)

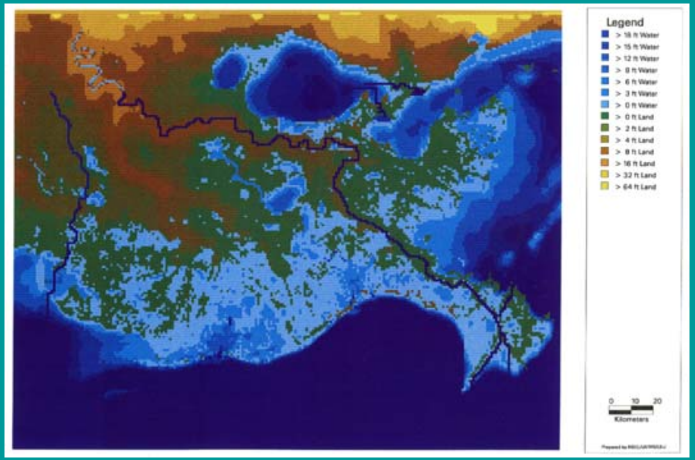
Modeling the effects of sea-level rise on the Louisiana coast



1878



1993



2090

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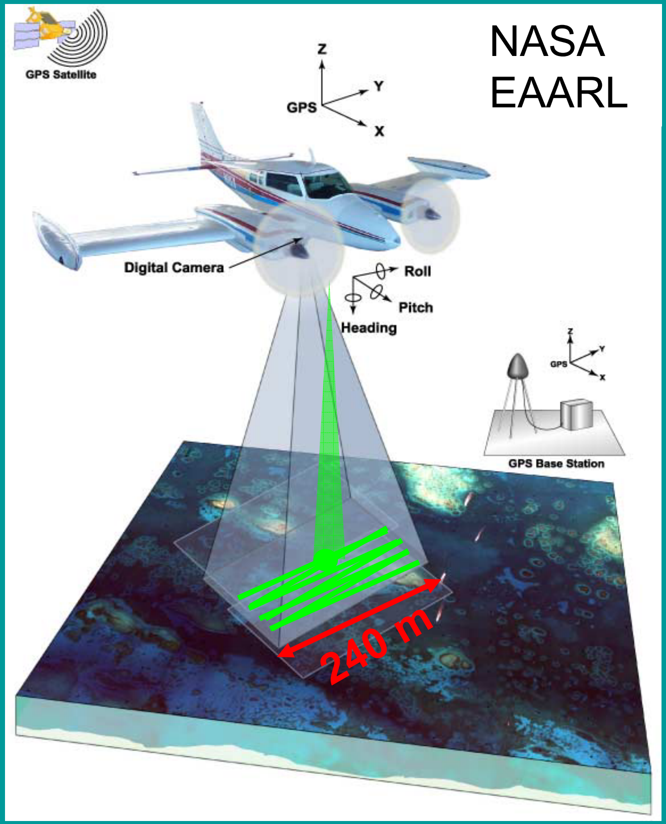
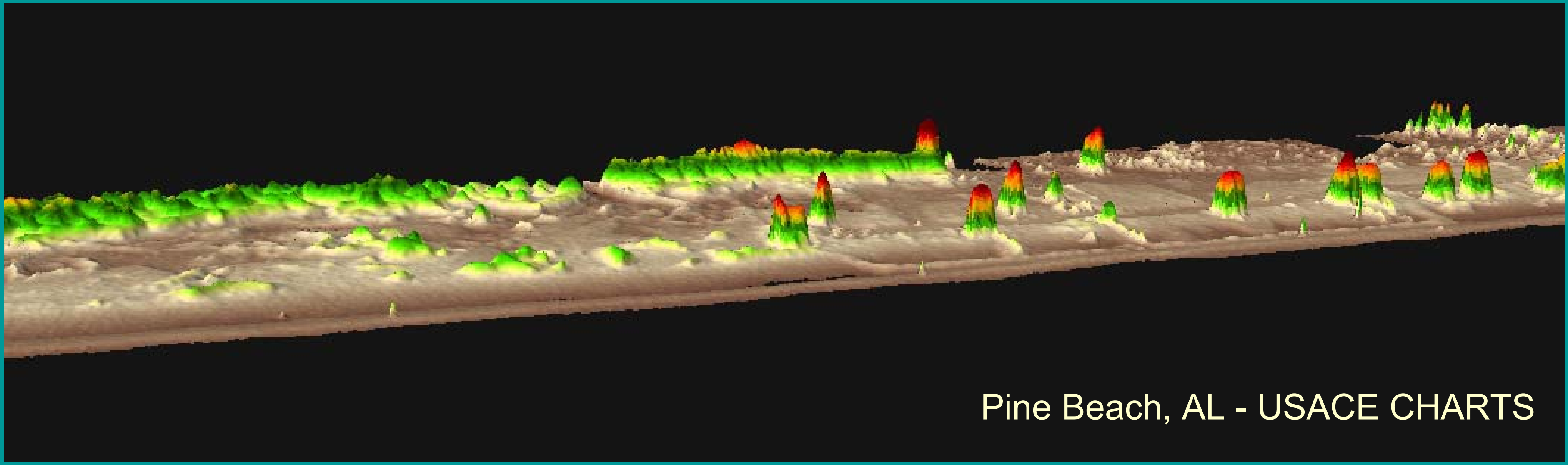


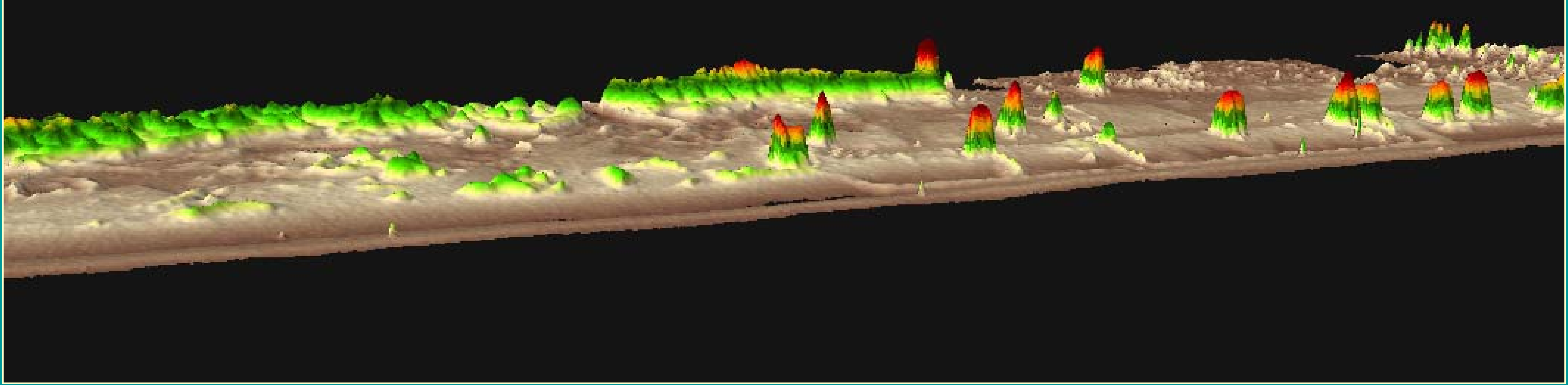
Lidar topographic surveys

- GPS-based
- 15 cm rms vertical accuracy
- laser shot collected every ~1 m^2
- surveys 100s of km in one day; swath width = 350 m

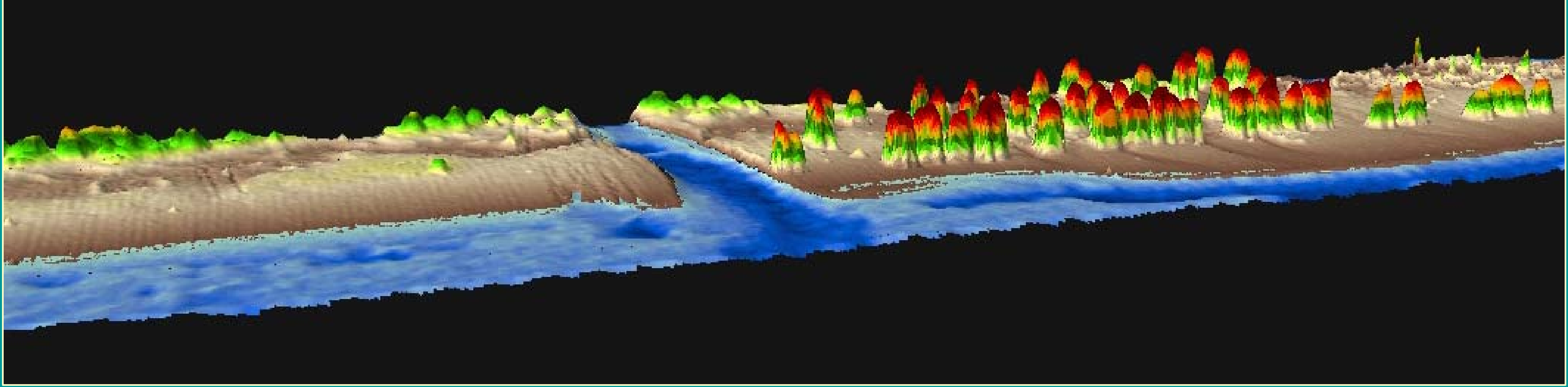


Can we predict which areas are most vulnerable to extreme coastal change?

Pre-Ivan Lidar Topography --USACE CHARTS



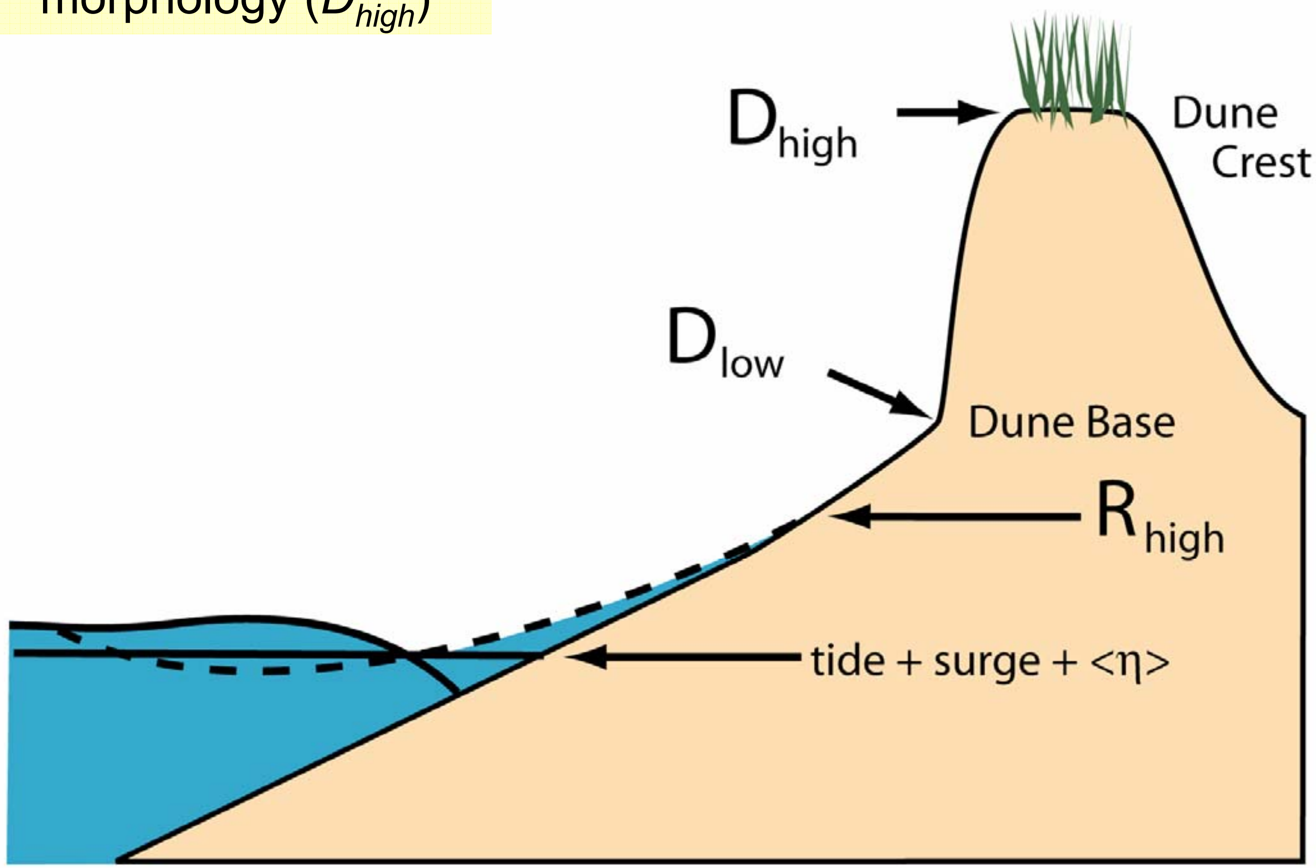
Post-Ivan Lidar Topography--NASA EAARL



Pine Beach, Ala. 1998 and Sept 2004

Storm-Impact Scaling Model

$$\frac{\text{fluids } (R_{high})}{\text{morphology } (D_{high})}$$

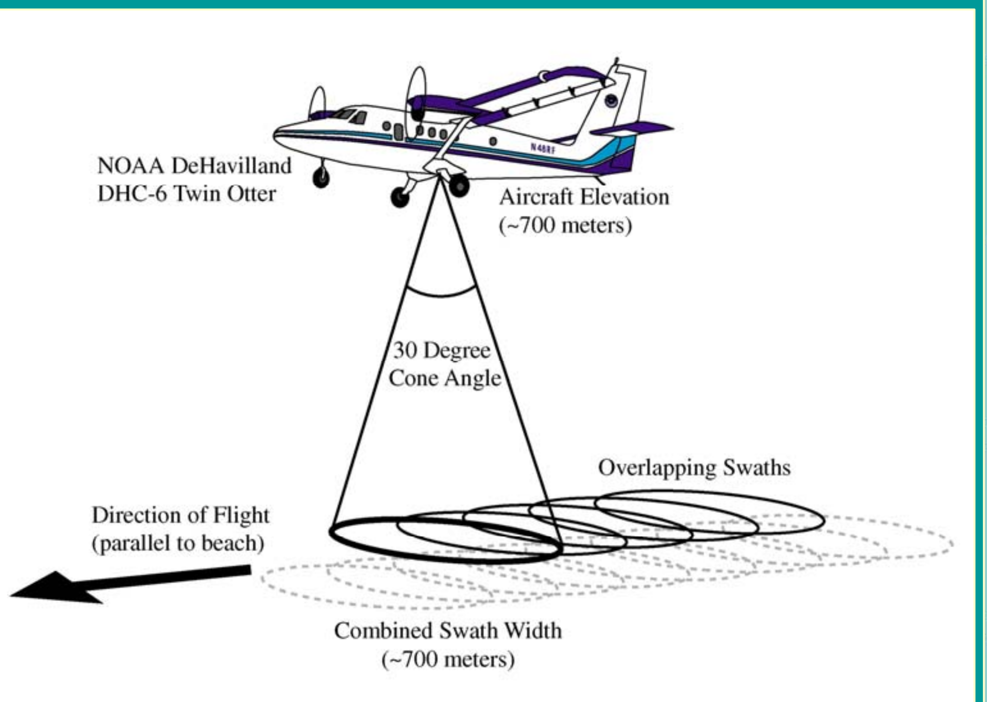


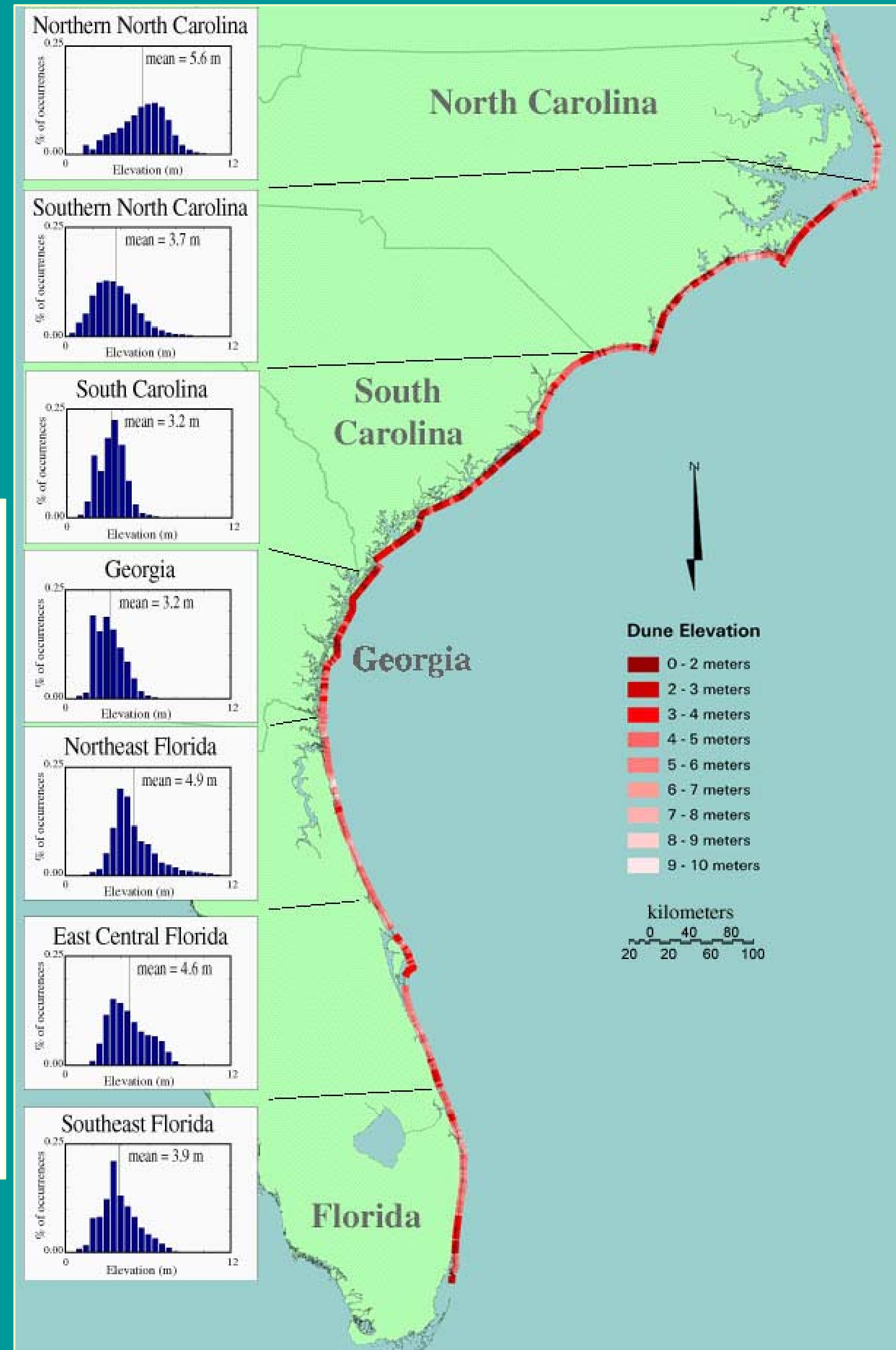
(modified from Sallenger 2000)

Storm-Impact Regimes

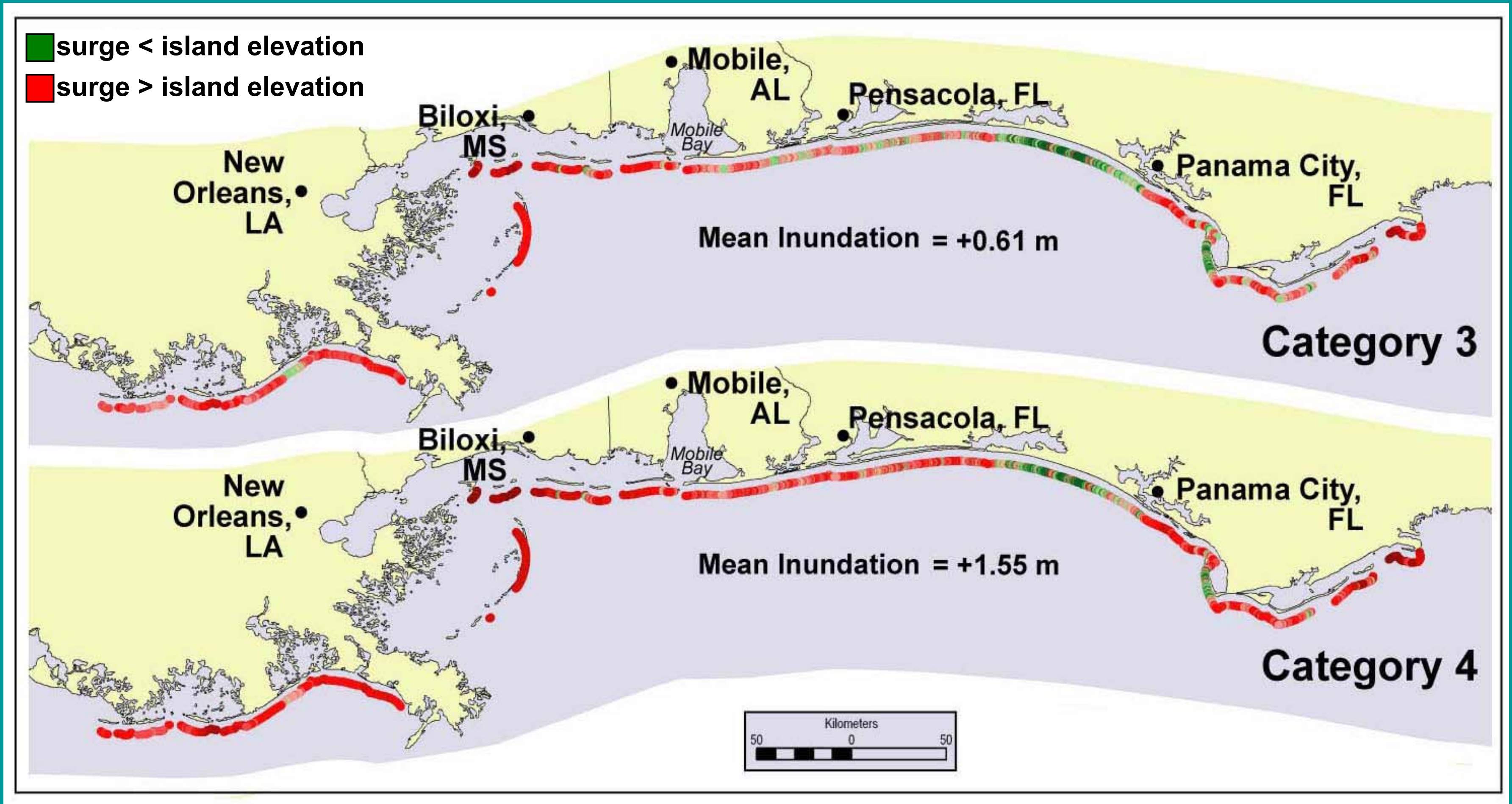
Sallenger 2000

Measuring dune elevations (D_{high})





Storm inundation potential



From H. Stockdon and A. Sallenger (USGS)

Relative Coastal Vulnerability of National Park Resources to Sea-Level Rise

Motivation

- The rate of eustatic SLR is expected to accelerate based on studies considered by the IPCC.
- The best estimate of SLR rate for the 21st century is 4.8 mm/yr, more than double the rate for the past 100 yr ~1.8 mm/yr.

http://www.stockpix.com/stock/environmentalissues/

Objectives

- Highlight areas where coastal change as a result of sea-level change may most likely occur.
- Provide NPS with a quantitative tool to assist in managing resources that may be vulnerable to SLR.

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CVI Variables and Sources of Data

Geologic Variables

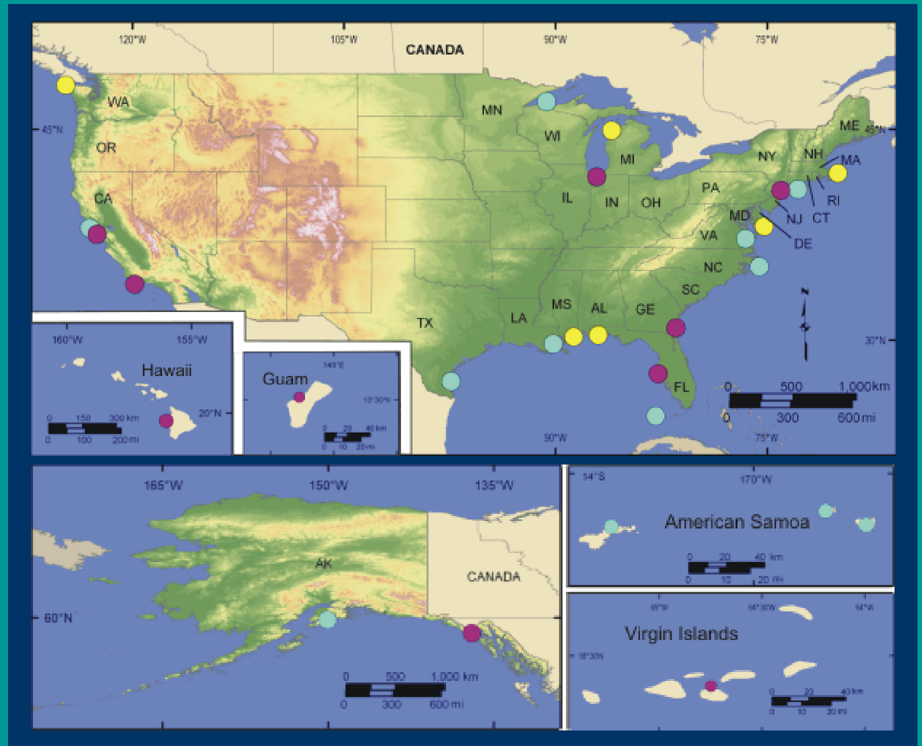
Physical Process Variables

VARIABLES	SOURCE
GEOMORPHOLOGY	Aerial Photography from MassGIS and USGS http://edcwww.cr.usgs.gov/ http://www.state.ma.us/mgis/
SHORELINE EROSION/ACCRETION (m/yr)	USGS Administrative Report: The Massachusetts Shoreline Change Project: 1800s -1994 (Thieler et al., 2001) http://www.state.ma.us/czm/shorelinechange.htm
COASTAL SLOPE (%)	NGDC Coastal Relief Model Vol 01 12/17/1998 http://www.ngdc.noaa.gov/mgg/
RELATIVE SEA-LEVEL CHANGE (mm/yr)	NOAA Technical Report NOS CO-OPS 36 SEA LEVEL VARIATIONS OF THE UNITED STATES 1854-1999 (Zervas, 2001) http://www.co-ops.nos.noaa.gov/publications/techrpt36doc.pdf
MEAN SIGNIFICANT WAVE HEIGHT (m)	North Atlantic Region WIS Data (Phase II) and NOAA National Data Buoy Center http://bigfoot.wes.army.mil/u003.html http://seaboard.ndbc.noaa.gov/
MEAN TIDE RANGE (m)	NOAA/NOS CO-OPS Historical Water Level Station Index http://www.co-ops.nos.noaa.gov/station_index.shtml?state=

NATIONAL PARKS STUDIED in COASTAL VULNERABILITY INDEX (CVI) ASSESSMENT

PACIFIC COAST
Channel Islands NP
Golden Gate NRA
Olympic NP
Point Reyes NS

ALASKA
Kenai Fjords NP
Glacier Bay NPP



NORTHEAST
Assateague Island NS
Cape Cod NS
Colonial NHP
Fire Island NS
Gateway NRA

SOUTHEAST
Cape Hatteras NS
Cumberland NS
Virgin Islands NP

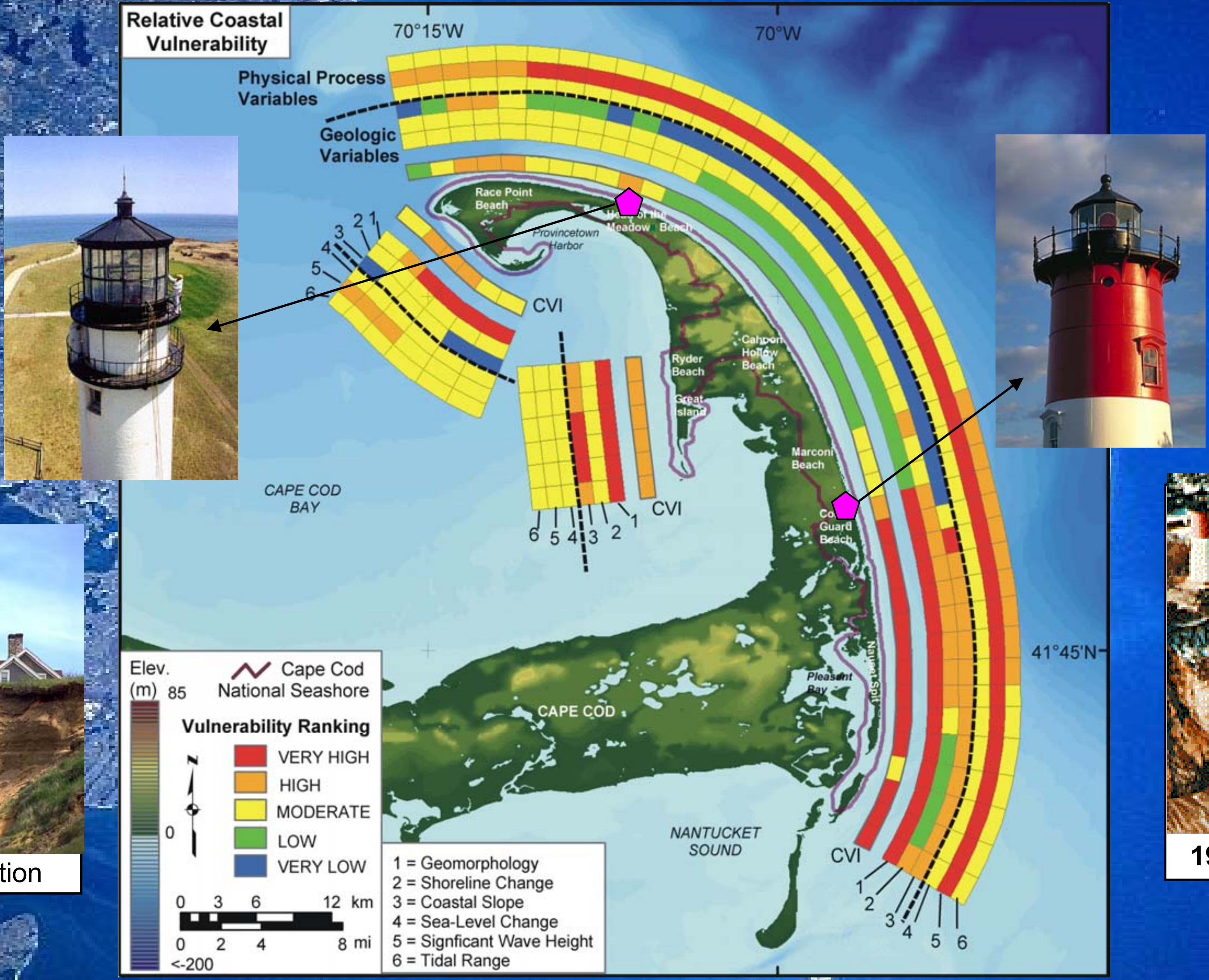
PACIFIC ISLANDS
Kaloko-Honokohau NHP
NP of American Samoa
War in the Pacific NHP

GULF OF MEXICO
Dry Tortugas NP
Gulf Islands NS
Jean Lafitte NHP
Padre Island NS
DeSoto NMEM

GREAT LAKES
Apostle Islands NL
Indiana Dunes NL
Sleeping Bear Dunes NL

mapped with USGS funding
mapped with Fee Demonstration funding
mapped with NRPP funding

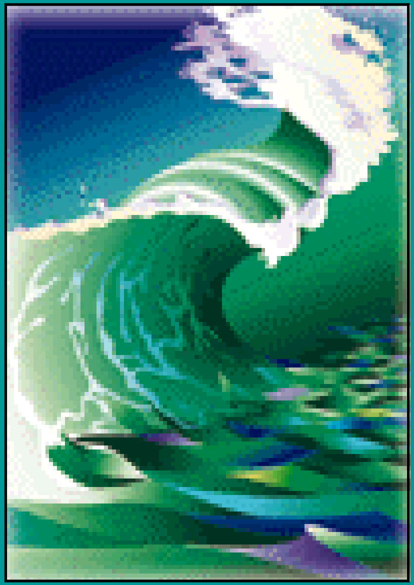
CVI Assessment for CACO



1996 location

1996 location

Conclusions



•Sea-level rise has been identified as a primary driver of coastal landloss globally and regionally. There is not yet scientific consensus on the impact of current and projected SLR on current or future rates of coastal erosion and inundation.

•However, scientific consensus is growing: climate change is warming the oceans globally, SLR is accelerating due to increased melting of glaciers and ice caps, and future SLR is likely to be toward the middle to higher ends of the IPCC estimates (0.48- 0.88m by 2100)

•Warming ocean temps are increasing energy levels of tropical storms, in addition to a natural cycle of increased storm activity that is likely to last ~15 years.

(NRC, 2002; Hansen, 2005; Alley, 2005; Church and White, 2006; Overpeck et al, 2006; Emanuel, 2006; Otto-Bliesner, 2006; Kolbert, 2006)

Questions

2005: A Record Hurricane Season

N.A. Hurricane season: 1June to 30 November

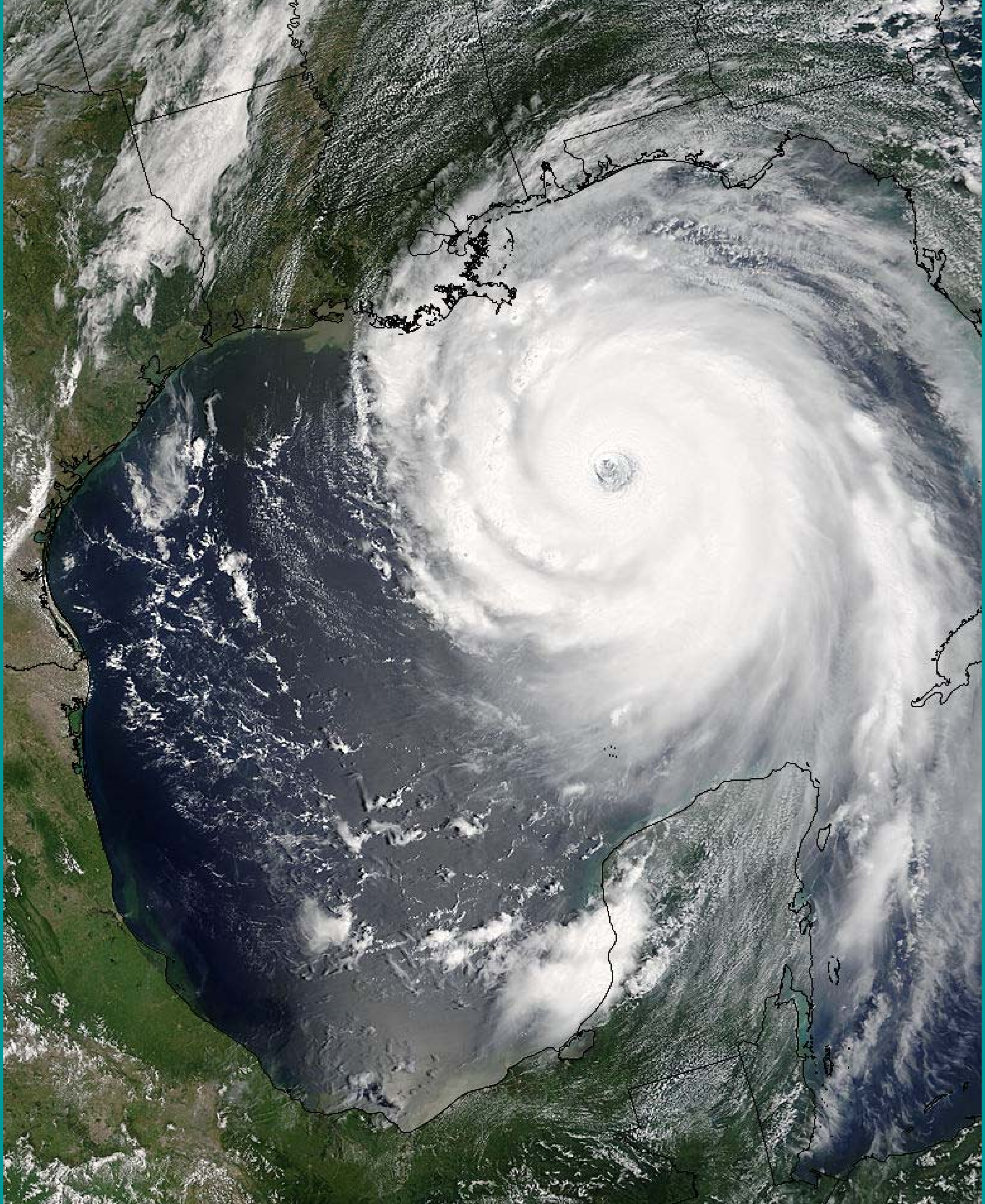
27 names storms, 15 hurricanes, three Category 5 storms

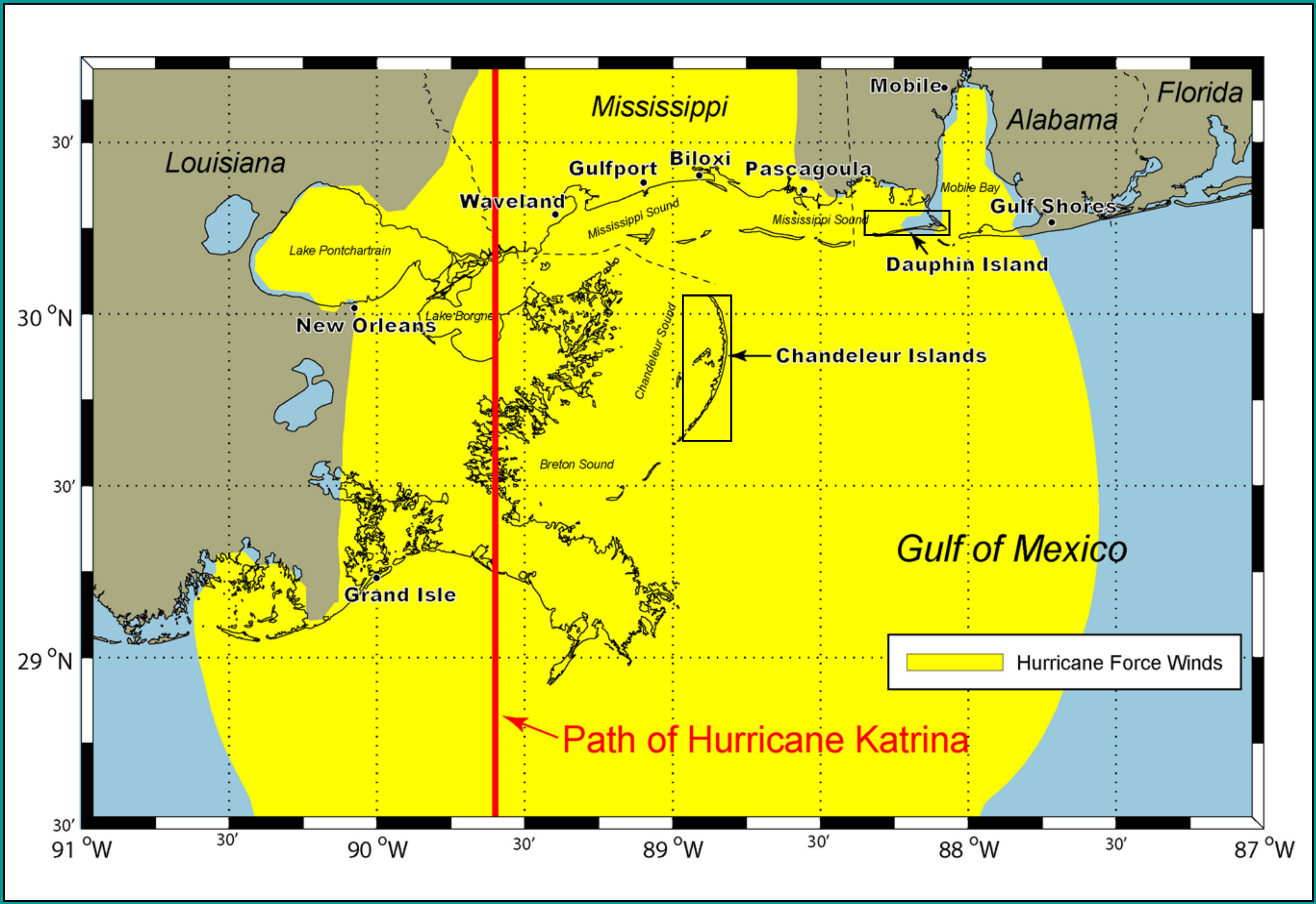
- 8 June, TS Arlene
- By 5 July, 4 named storms
- By 12 July, 5 named storms
- By 31 July, 7 named storms
- 29 Aug, Hurricane Katrina (Cat 5, 150 mph winds, 27-35 ft storm surge, 200 mi dia, 55 ft waves, 920 mb central pressure, 1336 fatalities/4000 missing, most costly)
- 21 Sept, Hurricane Rita (Cat 5, 155 mph winds, 15 ft surge)
- 19 Oct, Hurricane Wilma (Cat 5, 160 mph winds, 882 mb winds, most intense)
- 30 Dec- 6 Jan, TS Zeta

What will the 2006 storm season be like?

Hurricane Katrina
29 August 2005

Coastal change resulting from Hurricane Katrina provides us with a glimpse of what might happen to our coastal communities during the landfall of a major hurricane.





Wind data from NOAA Hurricane Research Division

Hurricane Katrina

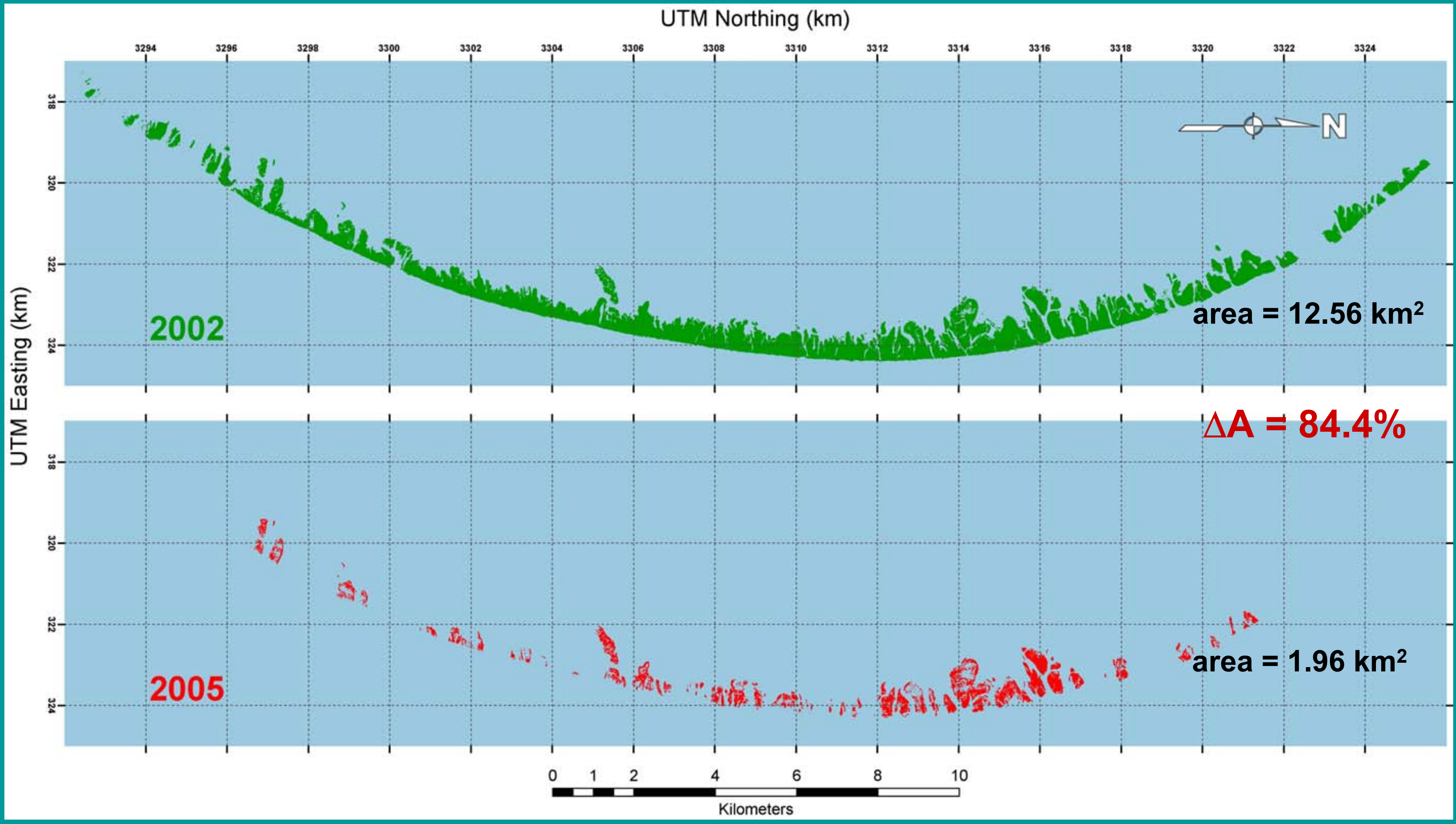
waves + storm surge = coastal erosion

Pre-Katrina

Post-Katrina

Before and after Hurricane Katrina, Gulfport- Biloxi, MS


Chandeleur Islands
Extreme Coastal Change… 85% Land Loss



The Coast of the Future

- Accelerated sea-level rise (50cm by 2100) due to climate change will flood coastal land, increase erosion, increase wetland loss…..

- Barrier islands, low-lying coasts and port cities will be at greater risk from flooding, coastal erosion, more intense storms, storm-surge flooding

- Ocean salt water will intrude farther into estuaries and coastal aquifers, harming wetland habitats and polluting fresh water sources

- The Gulf and Atlantic coasts and islands will be most vulnerable. Higher-elevation rocky New England and Pacific coast may see fewer impacts

- Use of coastal setbacks, easements, and “soft” engineering can protect shoreline integrity and public resources